Carderock Division
Naval Surface Warfare Center
West Bethesda, MD 20817-5700

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Survivability, Structures, and Materials Directorate
Technical Report

A Test Method for Dynamic Tear Testing of Titanium Plate using a Nonstandard Specimen

by

Michael E. Wells and Roy A. Lindauer

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The dynamic tear test is used extensively for characterization of the fracture toughness properties of both ferrous and nonferrous metals. This report describes a method for dynamic tear testing of titanium plate using a nonstandard 1-inch dynamic tear specimen. The dimensions and preparation of the specimen, a description of the apparatus and details of the testing procedure are given. The results of dynamic tear tests demonstrated that the nonstandard specimen accurately measures the fracture energy of titanium alloy plate. Use of this method is recommended for characterization of the fracture toughness properties of alpha-beta titanium alloys in cases of limited material availability.

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ABSTRACT

The dynamic tear test is used extensively for characterization of the fracture toughness properties of both ferrous and nonferrous metals. This report describes a method for dynamic tear testing of titanium plate using a nonstandard 1-inch DT test specimen. The dimensions and preparation of the specimen, a description of the apparatus, and details of the testing procedure are given. The results of dynamic tear tests demonstrated that the nonstandard specimen accurately measures the fracture energy of titanium alloy plate. Use of this method is recommended for characterization of the fracture toughness properties of alpha-beta titanium alloys in cases of limited material availability.

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ADMINISTRATIVE INFORMATION

This report was prepared as part of the Titanium VLI Evaluation Program under the sponsorship of Mr. J. Kryscnski, PMS 350. The work was supervised by Mr. R. DeNale, Head, Welding and NDE Branch, NSWC Carderock Division Code 615, under work unit 1-6150-008.

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INTRODUCTION

The Naval Sea Systems Command is currently evaluating the effects of heat treatment on the mechanical properties of titanium alloy Ti 6Al-4V plate. The 1-inch dynamic tear (DT) test will be used for characterization of the fracture toughness properties. The DT test was evolved at the Naval Research Laboratory in the early 1960's and a description of the test method is contained in reference [1]. Basically, the DT test involves a relatively large beam containing a brittle crack-starter weld on the tension side of the specimen. The brittle crack-starter weld is prepared by diffusing a small amount of embrittling material in an electron beam weld through the 1-inch plate thickness. The 1-inch DT specimen is fractured using a pendulum or drop-weight machine, and the total energy for fracture is recorded.

However, a limited amount of material was available for the heat treatment study. Thus, a test procedure was required using a nonstandard specimen that would generate the same energy values as measured in a standard 1-inch DT specimen. The objective of the work reported herein was to document the procedure used in fabrication of the nonstandard DT specimen and to demonstrate the adequacy of that specimen for measuring the fracture energy of titanium alloy Ti 6Al-4V plate.

TEST SPECIMENS

MATERIAL

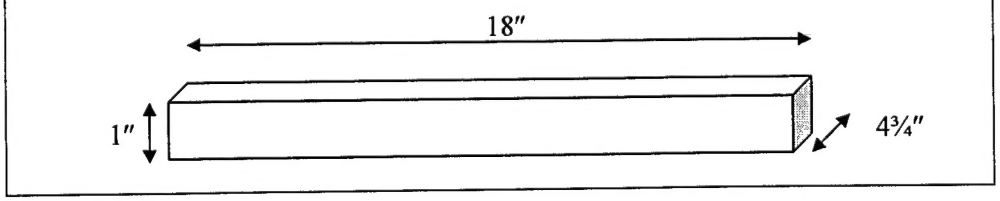
The commercial grade of titanium alloy Ti-6Al-4V was used in fabrication of both the standard and nonstandard 1-inch DT specimens.

STANDARD SPECIMEN SIZE

The standard 1-inch DT specimen is 1-inch thick, with a width of 4.75-inches and a length of 18-inches. The tolerances for these dimensions are provided in Table 1. For this work, four standard blanks were machined from a 1-inch thick Ti-6Al-4V plate.

Table 1. Dimensions of standard 1-inch DT blank.

Material	Thickness inch	Width inch	Length inch
Ti-6Al-4V	1.00 ± 0.06	4.75 ± 0.12	18.0 ± 0.12

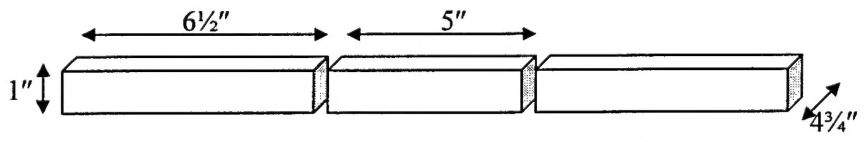


NONSTANDARD SPECIMEN SIZE

As noted previously, the nonstandard specimen was designed under the assumption that a limited amount of heat-treated material would be available for fracture toughness testing. The nonstandard specimen consists of a center test section and two end-tabs. The length of the center section is 5-inches. The length of each end-tab is 6½-inches, giving an overall specimen length equivalent to that of the standard 1-inch DT specimen. The thickness and width of the nonstandard specimen is the same as the standard DT specimen. The dimensions and tolerances for the nonstandard specimen are provided in Table 2. To fabricate four specimens, eight end-tabs and four center sections were machined from the same 1-inch thick Ti-6Al-4V plate.

Table 2. Dimensions of nonstandard 1-inch DT blank.

Material	Section	Thickness inch	Width inch	Length inch
Ti-6Al-4V	Center	1.00 ± 0.06	4.75 ± 0.12	5.0 ± 0.020
Ti-6Al-4V	End-tabs	1.00 ± 0.06	4.75 ± 0.12	6.5 ± 0.050



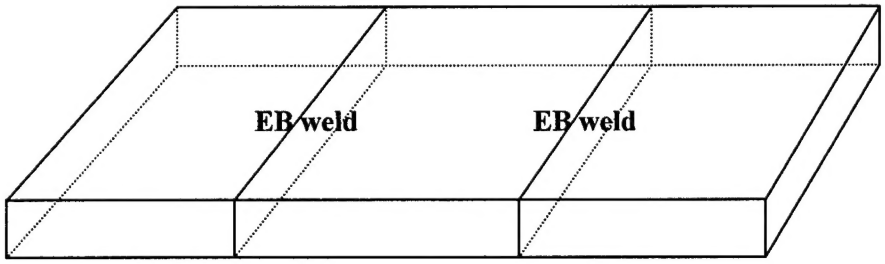
ELECTRON BEAM WELDING OF END-TABS

The nonstandard specimen blank was prepared by joining two end-tabs to the center section by electron beam (EB) welding. In preparation for EB welding, the side of each end-tab adjoining the center section was milled to ensure uniform contact. After machining, the joint surfaces were cleaned with methyl ethyl ketone (MEK), immersed in a room temperature acid etchant consisting of 45% nitric acid, 49% water and 6% turco 4104 for a period of 5 to 7 minutes, rinsed with tap water, rinsed with distilled water and air dried.

The center section and two end-tabs were aligned in a welding fixture. The center section was positioned with the rolling direction parallel to the width of the DT specimen. A seal weld was deposited on both sides of each butt joint to maintain alignment. An EB weld was then deposited on the top surface of the square groove. The penetration of the weld was measured as approximately 0.75-inches. The specimen was turned over and another EB weld was deposited on the groove surface to the same depth to ensure complete penetration. The EB welding parameters are provided in Table 3.

Table 3. Electron beam welding parameters for joining the end-tabs.

Weld	Kilovolts kV	Milli-amps mA	Focus	Deflection			Travel Speed IPM	Work Distance inch
				Beam Pattern #	Frequency Hz	Size inch		
Seal	150	15	Sharp	5 (circle)	800	0.025	30	10.5
Pass	150	15	Sharp	5 (circle)	800	0.025	15	10.5
Cosmetic	150	15	Sharp	5 (circle)	800	0.025	15	10.5



ELECTRON BEAM WELDING OF CRACK-STARTER WELD

Length of Crack-Starter Groove

The crack-starter weld is positioned to provide a 3-inch fracture path in the test material (T_m). Thus, the crack-starter weld extends for a length of approximately 1 ¾-inch. The crack-starter weld is prepared by machining a shallow groove along the centerline on each side of the specimen.

On both the standard and nonstandard specimens, the test material dimension was measured from the compression side and indicated with a marker. A 1/16-inch diameter ball mill was used to cut a 0.062-inch deep groove from the tension edge to the mark. The dimensions of the crack-starter groove are shown in Table 4 for a nonstandard DT blank. The only requirement for this machining procedure is that the groove does not extend into the test material. After cleaning the groove with MEK, a clean 1/16-inch diameter steel wire was placed in each machined groove and lightly hammered in place with a center punch. It is noted that any mild steel wire may be used as the embrittling material.

EB Welding

The specimen was aligned in a fixture for EB welding of the steel wire. A seal weld was deposited on both groove surfaces to ensure uniform contact of the steel wire with the titanium base material. An EB weld was then deposited on the surface of one groove. The penetration was measured at approximately 0.80-inches. The specimen was turned over and an EB weld was deposited on the

surface of the other groove to the same penetration depth. The parameters for EB welding of the crack-starter weld are provided in Table 5.

Table 4. Dimensions of crack-starter groove.

Parameter	Dimension, inch
Test material, T_m	3.0 ± 0.04
Notch width	0.062
Notch depth	0.062
Notch length	1.75 nominal

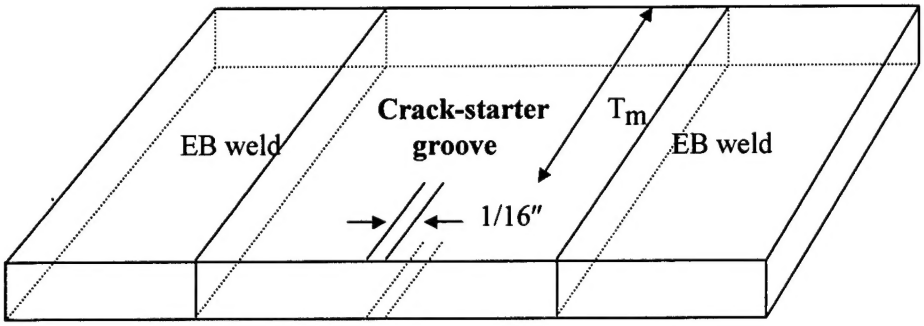


Table 5. Electron beam welding parameters for crack-starter weld.

Weld	Kilovolts kV	Milli-amps mA	Focus	Deflection			Speed IPM	Work Distance in
				Beam Pattern	Frequency Hz	Size in		
Seal	100	3	Sharp	8 (arrow)	800	0.04	30	11.0
Pass	100	40	Sharp	8(arrow)	800	0.40	15	10.5

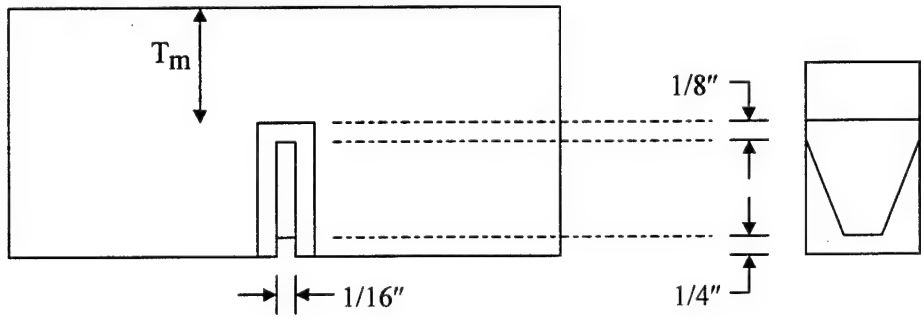
NOTCHING THE CRACK-STARTER WELD

The crack-starter weld on each specimen is notched to assist initiation of the crack in the brittle weld. The notch is prepared by sawing a trapezoid pattern on the tension edge and sides of the crack-starter in accordance with the dimensions provided in Table 6. The tension edge of each specimen is

notched first with a 0.062-inch thick saw cut along the centerline of the embrittled EB weld to a depth of 0.25-inches. The specimen was then positioned in an angle vise for saw cutting of the side notches, making sure that the saw cuts did not extend beyond the end of the EB weld into the test material (T_m). The only requirement for notching the crack-starter weld is that the notch be centered on the EB weld and that the side notches do not extend beyond the end of the EB weld. A scribed line, marked 0.125-inches from the end of the EB weld, can be used as a guide to terminate the saw cutting of the side notches. Figure 1 provides an overall view of the notched crack-starter weld and welded end-tabs in a nonstandard DT specimen.

Table 6. Dimensions of Notched Crack-Starter.

Parameter	Dimension, inch
Test Material, T_m	3.0 ± 0.04
Tension Edge Notch Thickness	0.062
Tension Edge Notch Depth	0.25



APPARATUS

SPECIMEN TEMPERATURE MEASUREMENT

All specimens were tested at a test temperature of 30°F ± 2°F. The specimens were placed in an insulated container and fully immersed in cold water for a period of one hour. A thermocouple was used to measure the bath temperature. Each specimen was removed from the bath with tongs and placed on the anvil of the test machine

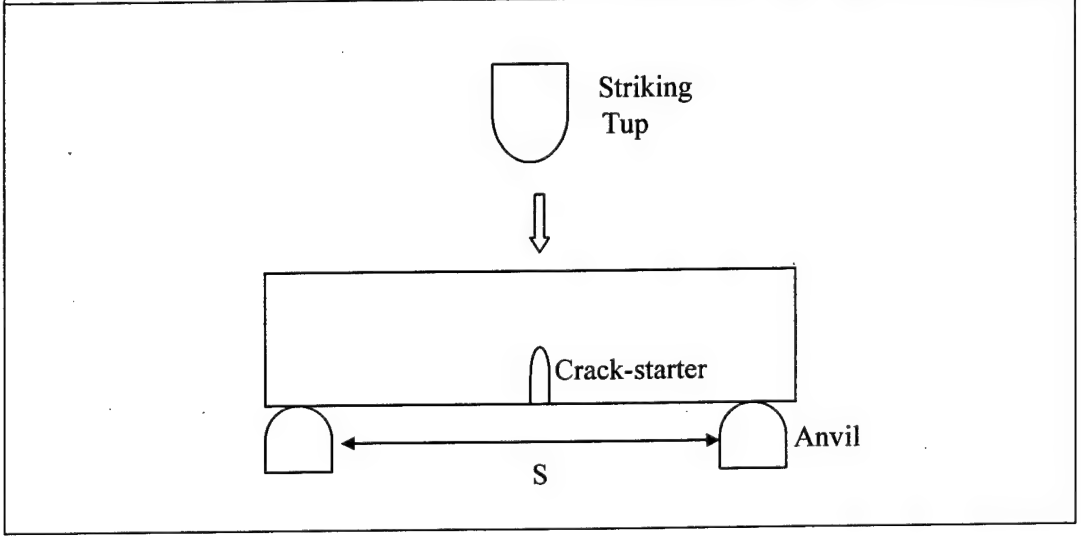
SINGLE-PENDULUM MACHINE

The single pendulum machine shown in Figure 2 was used for all dynamic tear tests. With a maximum vertical drop of 8.872 feet and a hammer weight of 1721.3 pounds, the machine is capable of producing up to 15,272 ft-lb of energy. Hammer rotation was measured on a laser etched indicating disc

to the nearest 0.1 degree. The machine specifications are provided in Table 7. Each specimen was positioned on the anvil so that fracture would propagate in the rolling direction of the plate.

Table 7. Single-pendulum machine specifications.

Parameter	Dimension
Vertical drop height	8.872 feet
Hammer weight	1721.3 pounds
Tup radius	1.0-inch
Anvil radius	5/8-inch
Support span, S	16-inches



RESULTS AND DISCUSSION

The test results for both the standard and nonstandard 1-inch DT specimens are provided in Table 8. The range in impact energy for commercial grade Ti-6Al-4Vis also provided for comparison. The energy values for the standard specimens ranged from 746 ft-lbs to 841 ft-lbs, with an average value of 790 ft-lbs. The energy values for the nonstandard specimens ranged from 687 ft-lbs to 890 ft-lbs, with an average value of 790 ft-lbs. These results clearly show that the nonstandard specimen accurately measures the fracture energy of Ti-6Al-4V plate material.

Visual examination of the test material surfaces on the nonstandard specimens revealed that the plastic zone extended for a distance of approximately ½-inch. Thus, the 5-inch width of the center section of the specimen was more than adequate for ensuring that all the plastic deformation was contained within this section of the specimen. The fracture face of a nonstandard DT specimen is shown in Figure 3. This figure also illustrates the appearance of the notching details of the crack-starter weld.

Table 8. One-inch dynamic tear results for Ti-6Al-4V plate.

Specimen Type	Specimen ID	Tear Energy ft-lbs	Fracture mode
Nonstandard	1	687	Mixed mode
	2	793	Mixed mode
	3	890	Mixed mode
	4	793	Mixed mode
	Average	790	
Standard	5	746	Mixed mode
	6	805	Mixed mode
	7	770	Mixed mode
	8	841	Mixed mode
	Average	790	
Range*		331-942	
*Range in impact energy for commercial grade Ti-6Al-4V using the 1-inch DT specimen.			

SUMMARY

The objective of this work was to demonstrate the adequacy of a nonstandard specimen for measuring the fracture toughness of titanium Ti-6Al-4V plate in lieu of the standard 1-inch DT specimen. The results of dynamic tear tests have shown that the nonstandard specimen can be used to accurately measure the fracture energy of this material. Use of the method described in this report is recommended for characterization of the fracture toughness properties of alpha-beta titanium alloys in cases of limited material availability.

FUTURE WORK

The method described in this work will be used to fabricate 1-inch DT specimens for a study of the effects of heat treatment on the fracture toughness properties of low oxygen, titanium alloy Ti6Al-4V plate materials.

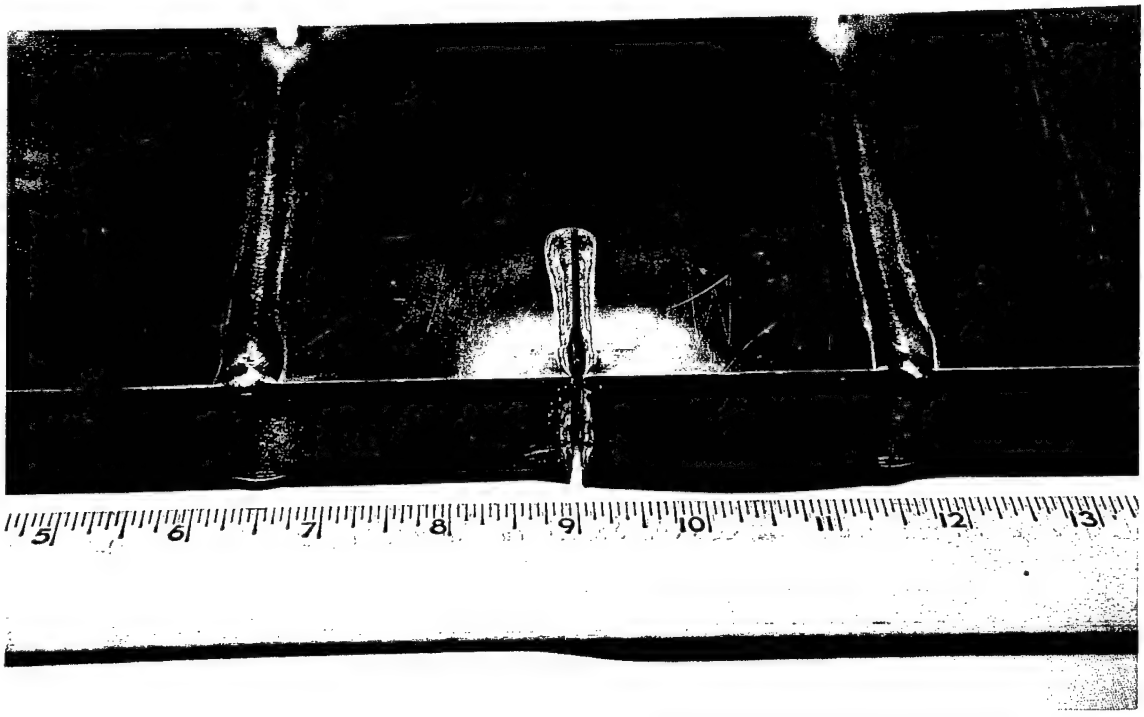


Figure 1. Nonstandard 1-inch DT specimen.

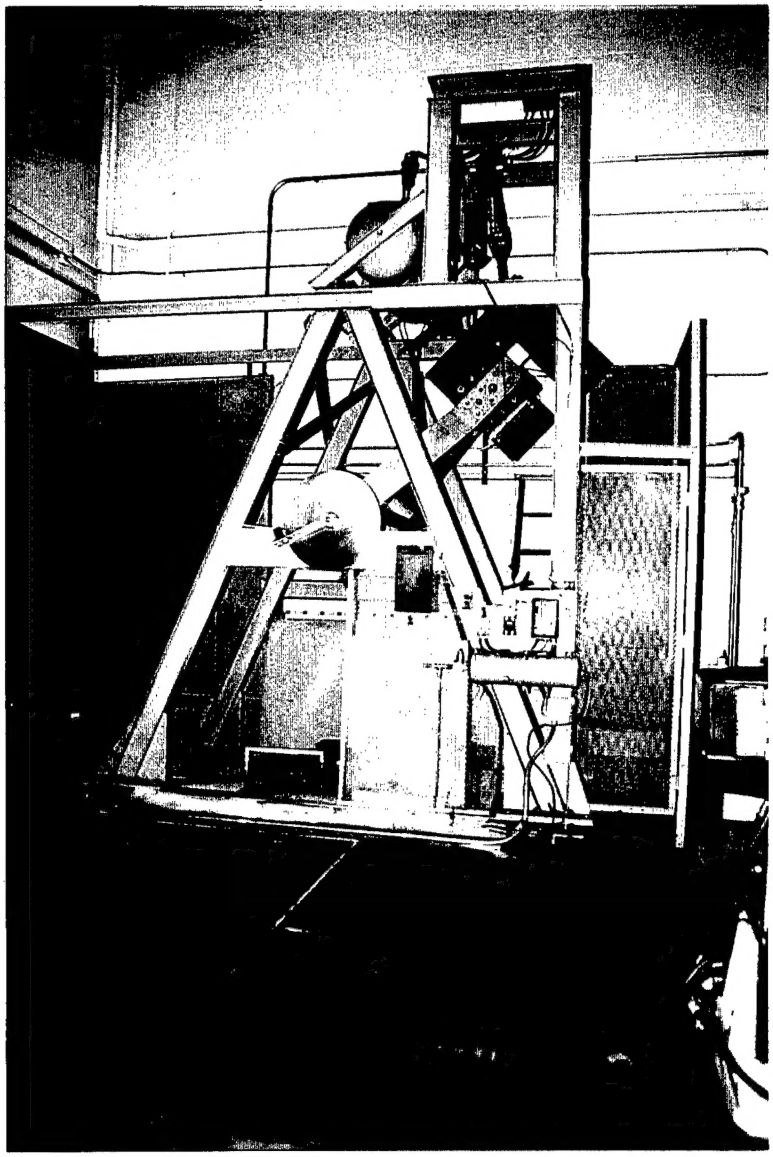


Figure 2. Single-pendulum machine for dynamic tear testing.

Figure 3. Dynamic tear fracture and crack-starter weld appearance.

REFERENCES

1. P.P. Puzak and F.A. Lange, *Standard Method for the 1-Inch Dynamic Tear Test*, NRL Report 6851, Feb 1969.

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